Detection: You need to know they are there before you can shoot them

- Some definitions
- First Things First (does a LOS exist)
  - Close fight (terrain)
  - At sea (OTH)
- The Glimpse Model (the simplest)
- The Continuous viewing model
- A data driven approach (e.g., the DYNTACS model)
- Radar Range Equation (RRE)

In order to shoot them we must (should) first acquire/identify them

- Koopman defines detection as, "that event constituted by the observer's becoming aware of the presence and possibly of the position and even in some cases the motion of the target."
- Other research has distinguished several levels of target acquisition as hinted in the above definition:
  - **Cueing Information:** provides the approximate location for further search (e.g. a gun flash).
  - **Detection** means that an observer decides that an object in his field of view has military interest (e.g. he distinguishes a vehicle from a bush).
  - **Classification** occurs when the observer is able to distinguish broad target categories (e.g. tracked vs. wheeled vehicles).
  - **Recognition** allows discrimination among finer classes of target (e.g. tank vs. armored personnel carrier).
  - **Identification** provides precise target identity (e.g. distinguish between an M60 tank and an Ml tank).
- Analysis can be very sensitive to this! What level must he be to shoot at? If IFF is played this is easier.
- Lots of other taxonomies

Modeling detection/acquisition is very complex

- Analysis can be very sensitive to this! What level must he be to shoot at? If IFF is played this is easier.

- Target acquisition is a complex phenomenon that cuts across many scientific disciplines:
  - Physics of the electromagnetic spectrum,
  - Meteorology of atmospheric transmission,
  - Electronics of sensor devices,
  - Optics of imaging sensors,
  - Physiology of human vision,
  - Psychology of human response to detection stimulus.

What's needed to acquire a target

- To acquire a target

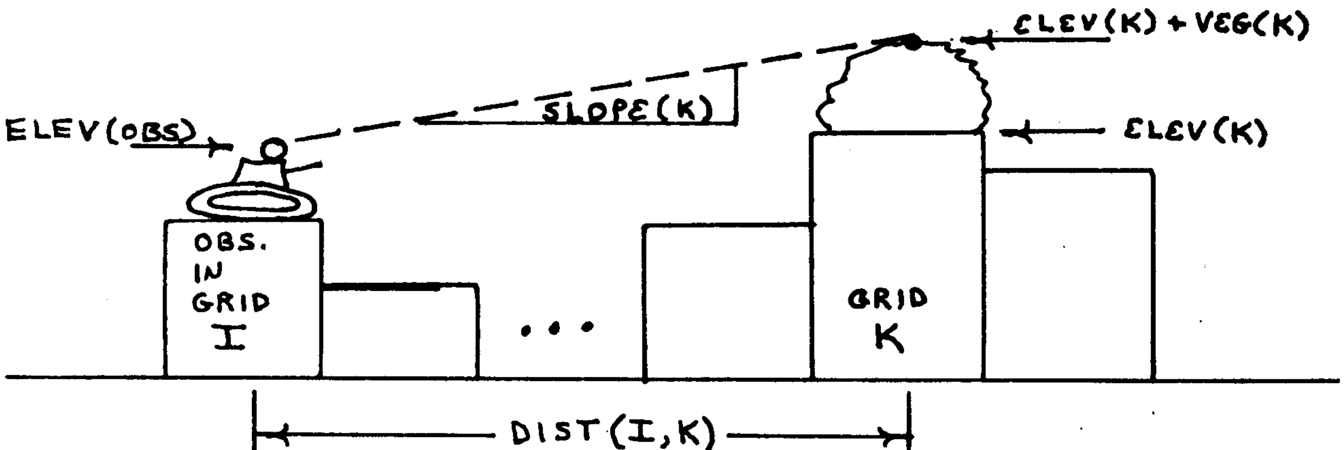
  1. Physical requirements:
     - line-of-sight (LOS)
     - The target signature must be greater than the sensor threshold
     - The sensor must be pointing in the right direction.

  2. Koopman: "Even when the physical conditions make detection possible, it will by no means inevitably occur." Thus models of target detection are invariably stochastic models. Such models specify a probability of detection (depending on various observation conditions) or the distribution of the random time required until detection occurs.

Detection requires that a LOS exists

- Calculate LOS before doing other calculations
  - Do for each possible sensor/target pair
  - Can do gross filtering first
- Uneven terrain
  - critical in close quarters land combat
- Curvature of the earth (over the horizon)
  - critical for long range detection (Air/Sea)

Grid Terrain models (Basic Idea)



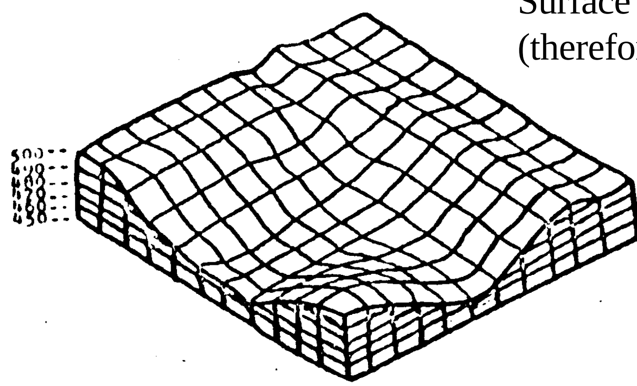
- Simple Algorithm to find if LOS exists (other algorithms exist)
  - (1) If observer and target are in the same grid or in adjacent grids, then assume that LOS exists and terminate the computations.
  - (2) If observer and target are not in the same or adjacent grids, then identify all the grid cells that are intersected by the observer-target line (grid cells between observer and target).
  - (3) For each intermediate grid cell (call it grid cell k) identified in step 2, compute the slope of the line from the observer to the terrain of grid cell k. Note: the distance between grid cells is taken as the center to center distance or all the boundary intersections.
  - (4) Compare each such SLOPE(k) to the slope from observer to target: If any SLOPE(k) is greater than the observer-target slope, SLOPE(tgt), then the terrain in grid cell k blocks the LOS. Otherwise, LOS exists.

  - Easy to extend to two dimensions (find blocks that cross)--CASTFOREM uses this approach (Bresenham)

Explicit Surface Terrain Models (continuous)

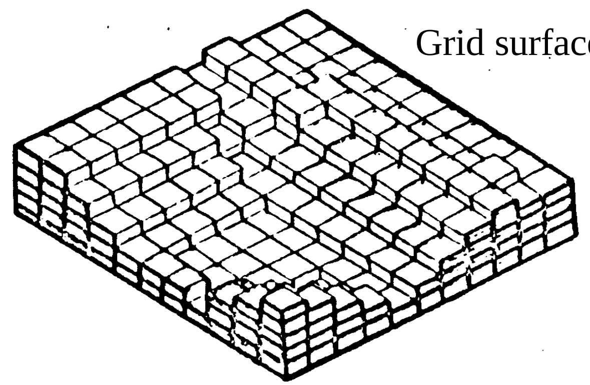
- Idea draw picture (3 points makes a triangle)
- LOS calculations are similar, except that the slopes are calculated at the intersection points.
- Good for graphics

Surface = interconnected triangles
(therefore is continuous)



Grid surface

Dyntacs ->



ModSAF

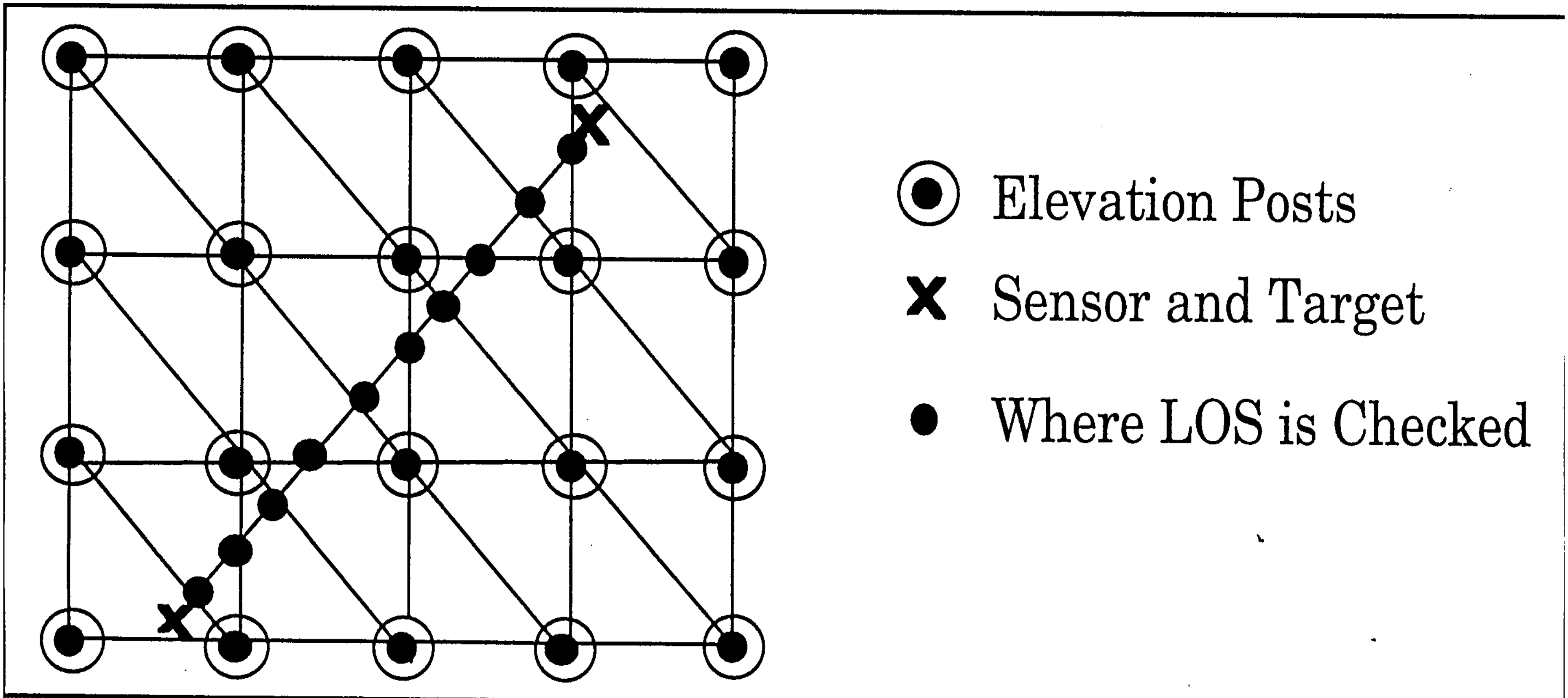


Figure A-1. ModSAF LOS

JANUS

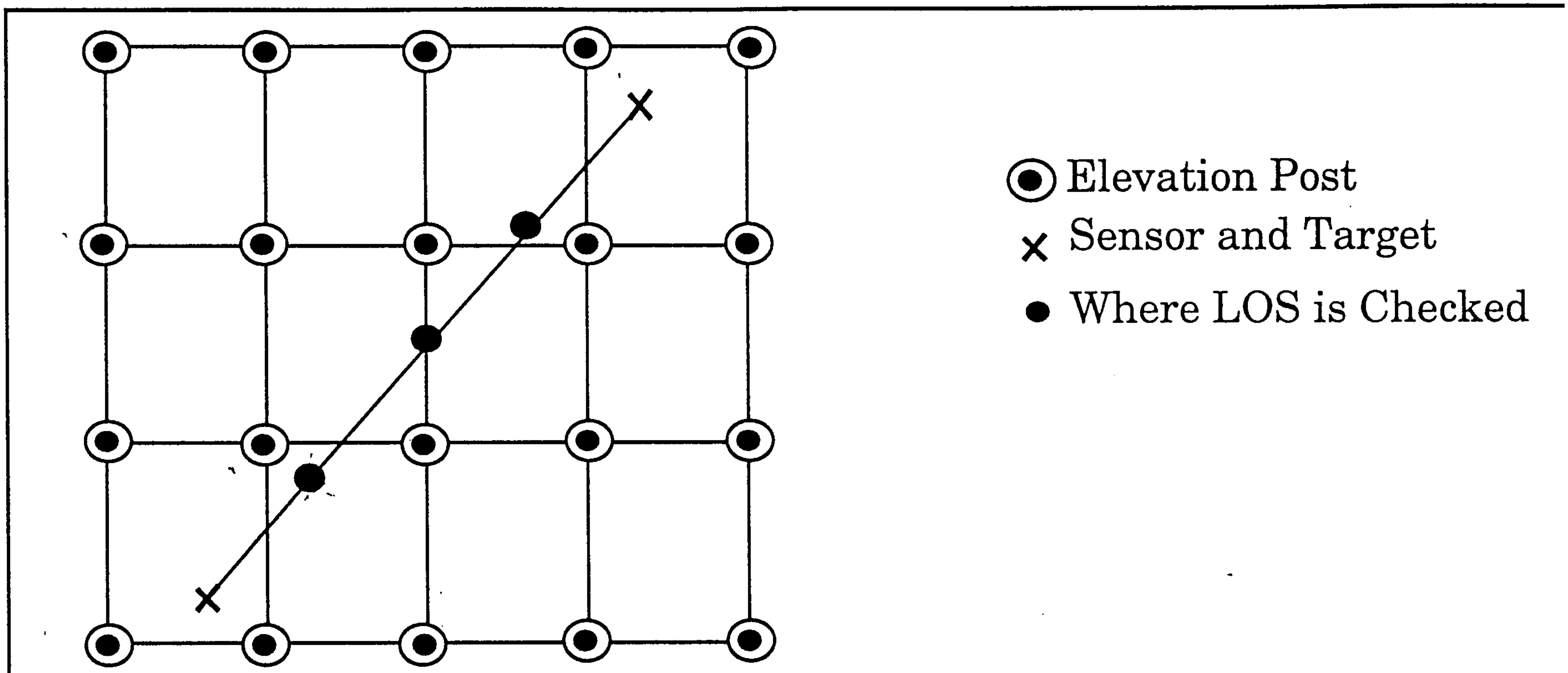


Figure A-4. Janus LOS

The Janus LOS algorithm is faster than ModSAF and DYNTACS because it requ
fewer calculations. However, it is the most unstable of the three interpolative LOS

Dyntacs

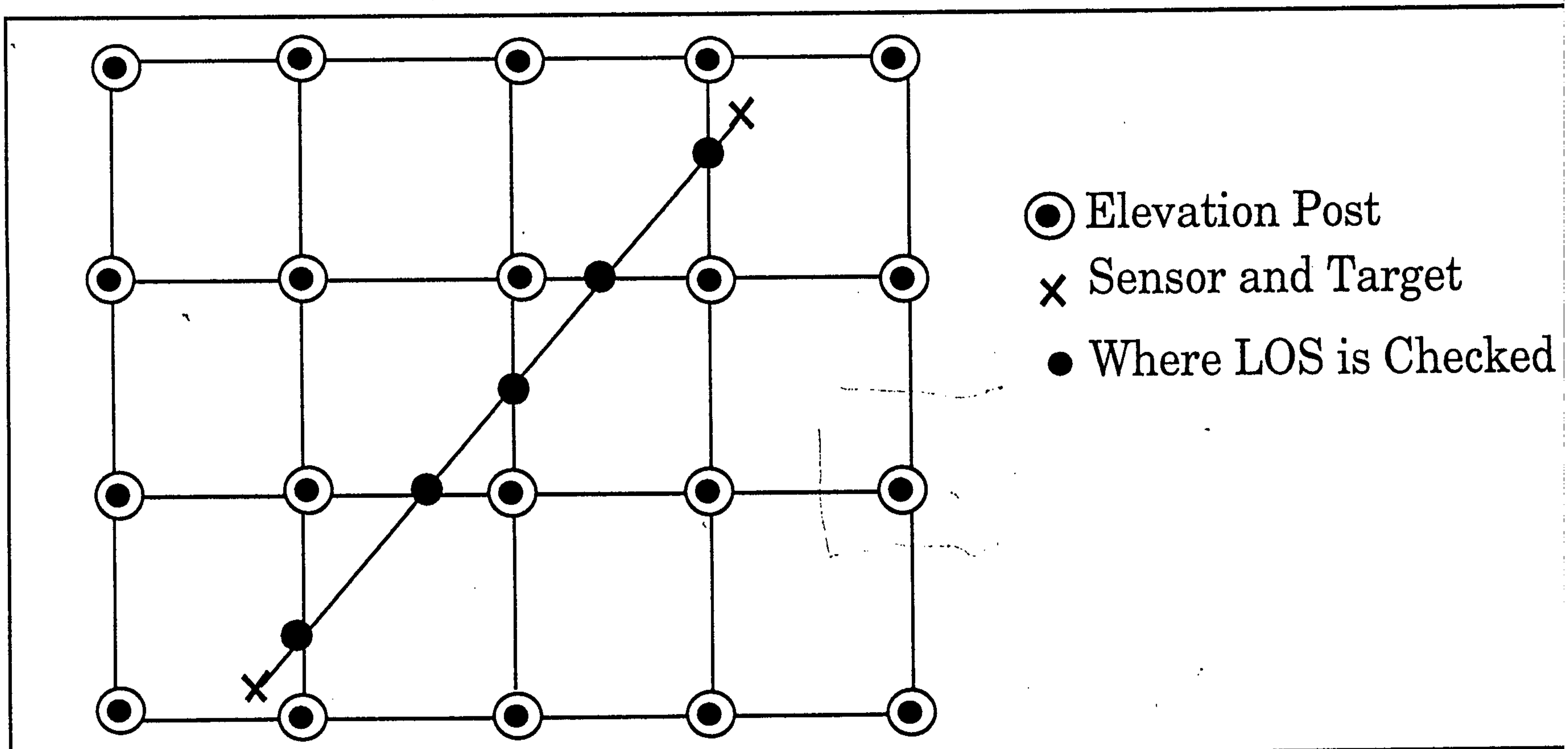


Figure A-3. DYNTACS LOS

Note: CASTFOREM uses grid centers and is the fastest

Timing Comparisons

- CASTFOREM aka Bresenham, (relative speed = 1.00)
  - uses center of grid cells to calculate elevations
  - determine which cells intersect
- JANUS (relative speed = 3.09)
  - samples along path (4-way interpolation of cells sampled to get elevations)
- DYNTACS (relative speed = 4.80)
  - use linear interpolation at the intersection of all cell edges, and 4 way interpolation to get sensor/target elevations
- ModSAF (relative speed = 5.02)
  - use linear interpolation at the intersection of all triangles

Okay, let’s move to PD|LOS exists

- Glimpse model
- Continuous viewing model
- Dyntacs model (based on experimental data)
  - Visual detection
- The Radar Range Equation

Start Simple: The Glimpse Model

- Suppose that an observer has intermittent chances to detect a target. For example, an observer who is scanning along a wood line in search of enemies will scan past the location of a target once per pass. A rotating scan radar will have its beam on the target once during each rotation. We call each such intermittent opportunity to detect, <u>a glimpse</u>.

- Index the successive glimpses i = 1, 2, …; starting when the search begins. Let g_i = the probability of detection of the target on the ith glimpse, (assuming that the search is still continuing, i.e. that the previous i-1 glimpses have failed to detect the target, and assuming that a target is present.)

- Each glimpse can be considered to be a Bernoulli trial with success probability g_i.

The mathematics of the glimpse model

- Let g_i = Pr(acquire on ith glimpse)
- Then, P(first detect on nth glimpse) = $$g_n \times \prod_{i=1}^{n-1} (1 - g_i)$$
- What if g_i = g for all i (I.e., situation remains the same)?
  – Note: in practice g_i changes as the scenario evolves
- Then, the number of glimpses until a detection ~ Geometric(g)
- Easy to draw a random variable to get the time to detect!
- E(# glimpse until detection) = 1/g
- Var(# glimpse until detection) = (1-g)/g^2
- Note: MLE estimate of g = 1/xbar as

How do we determine g_i?

- (1) If we are interested in the behavior of g under different observational conditions, we could set up a series of <u>experiments</u> for each observational condition and <u>table</u> the resulting set of g estimates.

- (2) As an alternative to the above experiments for different observational conditions, we can develop <u>models</u> which attempt to analytically explain the dependence of g on various observational factors.

How to simulate acquisition events

- time step
- event driven /* use cumulative CDF */

- My experience: if the objects’ movements are dynamic (state dependent), then it is easier to model a periodic “detection opportunity event” than a “detection event”
  – Most (all?) multi-platform models do this.

The Continuous Viewing Model

- The continuous looking model is based on a <u>detection rate function</u>, $D(t)$, with: Pr(detect in $[t, t + \Delta T]$) = $D(t) \quad \Delta T$
- For initial simplicity assume for now that $D(t) = D$, for all t, and Markov assumption.
- Then Pr(detect in $[t, t + \Delta T]$) = $D \quad \Delta T$
- Pr(Don't detect in $[t, t + \Delta T]$) = $1 - (D \quad \Delta T)$
- Pr(Don't detect in N independent ΔT steps) = $1 - \Pi(1 - (D \quad \Delta T))$
- Let $T = N \quad \Delta T$, then Pr(Don't detect in time T) = $1 - (1 - (D \quad T/N))^N$
- As N -> with $N \quad \Delta T = T$, Pr(detect in length T) = $1\text{-}e^{-DT}$
- Therefore, time to detect is exponential with rate D, so E[time to detect = 1/D]! Easy to simulate!
- If $D(t)$ is not a constant,

then Pr(detect in length T) = $1 - e^{-\int_{u=0}^{u=T} D(u)du}$

How do I find the detection rate D(t)?

- Two basic approaches
  - (1) Experimental data,
  - (2) Physics “like” equations

- Experimental data; The DYNTACS model:
  - “The DYNTACS target detection experiments were performed on several Army ranges at Fort Knox, Kentucky. M60 tanks were used as the targets to be detected. Experiments were conducted both with moving and stationary tanks. All experiments were done under daytime, clear environment observation conditions. The maximum target range was about 1.5 kilometers. The observers were stationary, not in vehicles. Observers searched a restricted 30 degree field of view using unaided vision.”

DYNTACS model of D

- Using regression techniques:

- $D = Pk \quad \{-0.003+[1.088/\text{DENOMINATOR}]\}$

- Where: $\text{DENOMINATOR} = 1.453 + \tau \ (0.05978 + 2.188 \ R^2 - 0.5038 \ CV)$

  With:

  – τ = terrain complexity code. τ takes on values from 1 to 7 and is interpreted as the number of potential avenues of advance for the enemy in the observed scene.

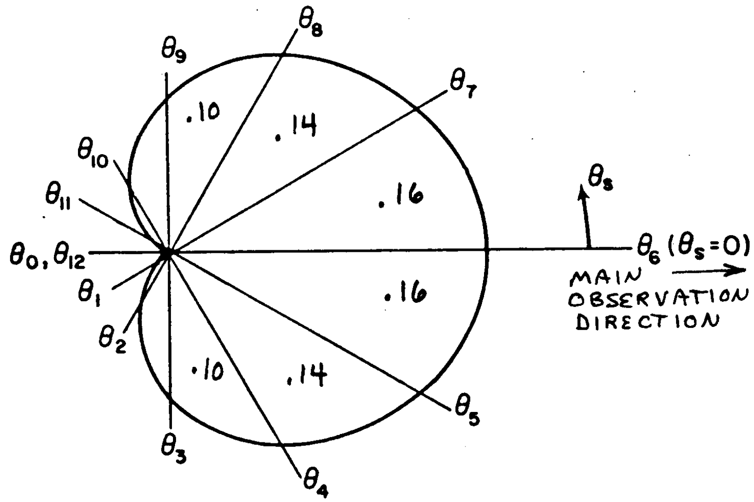
DYNTACS model of D (continued)

- R = apparent range in kilometers. R takes on values between 0.31 and 1.57 kilometers in the experimental data. The apparent range is the range at which a fully exposed M60 tank would present an image which is the same height as the image that is observed for the current target. R can be computed as R = (actual range   M60 height) / (target height   percent visible).

- CV = crossing velocity in meters per second.

- Pk is the probability that the observer is looking in the 30 degree search sector which contains the target. (see picture on next slide)

DYNTACS model cardiod of viewing distribution

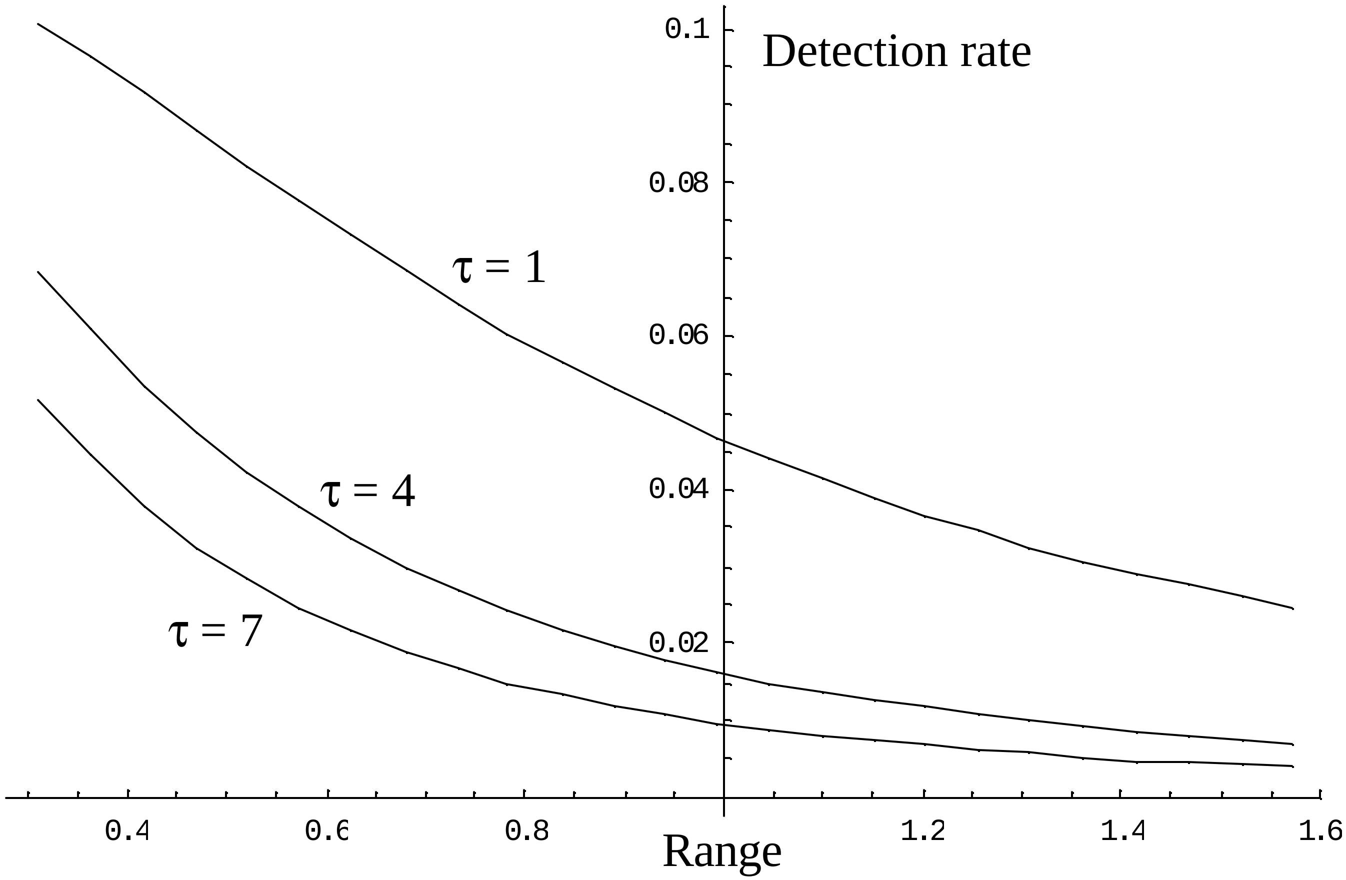


Values of P_K for Cardoid Distribution

K	P_K
1	.0037
2	.0250
3	.0620
4	.1047
5	.1416
6	.1630
7	.1630
8	.1416
9	.1047
10	.0620
11	.0250
12	.0037
	1.0000

Example

- For a fully exposed M1 tank in front of you (pk = .16) moving directly at you (cv = 0). Let's vary τ and r.



Example usage

- Suppose $\tau = 4$ and $r = 1$, then $D = .0161878$
- The Dyntacs model assumes that the detection rate is constant in 30 to 60 second intervals (even for moving targets), use 30 second time steps. (could use other trading accuracy for speed)
- Using the continuous looking model that probability of acquisition in T is 1. - exp{-D*T)
- = 1. - exp(-.0161878*30) = .384692
- Finally, Dyntacs does a Bernoulli trial to determine if a detection is made in this periodic "detection opportunity event."

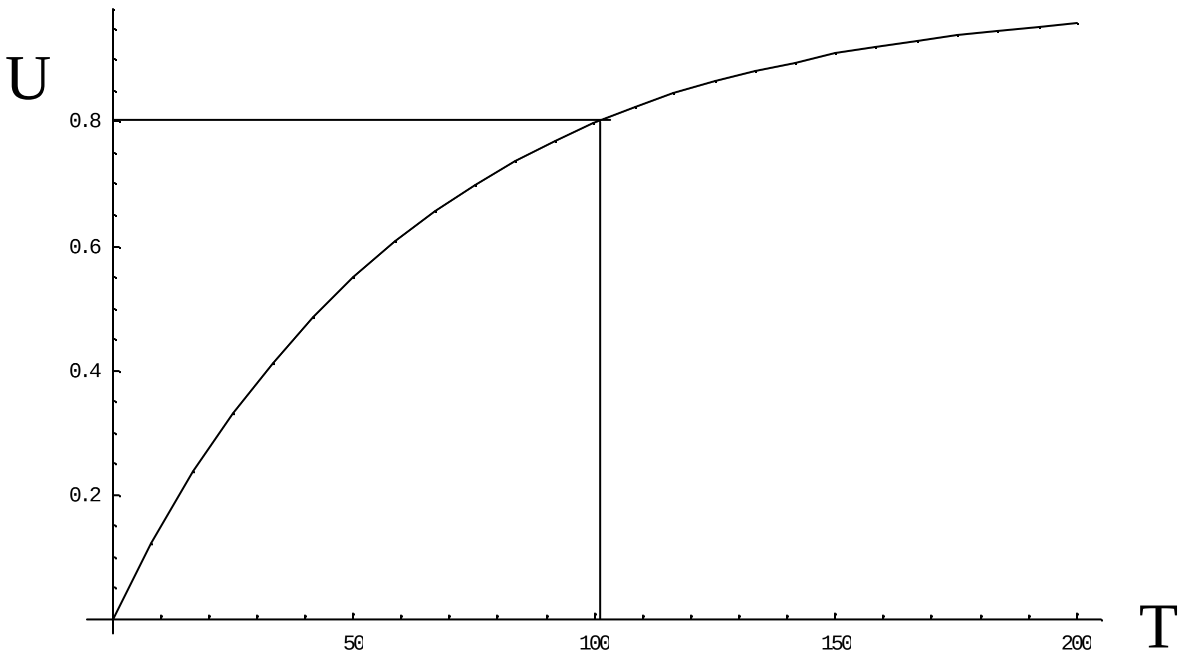
- Repeat for next detection opportunity event (all observers, all targets)

Better to schedule detection event

- Close combat depends critically on who sees who first. In my experience, 30 seconds can be too big a time step.
- Schedule detection event, given rate, assuming time to detect is exponential(1/D)
- Use uniform random draw and inverse transform to get time of detection.
- Need to schedule detection rate change events when r, cv, τ, or pk change “sufficiently” or if objects are moving in terrain so LOS needs to be constantly checked (hard to determine in advance when LOS will be lost/obtained). If rate or LOS changes, need to deschedule/reschedule detection events.
- If objects are moving a lot with terrain this can be burdensome

Example Calculation

- D = .016
- Random time to detect (T) is exponential with parameter 1/D.
- U = F(X) = 1. - exp{-DT}
- ==> T = -ln(1-U)/D
- Suppose U = .8, Then, 1-U = .2, and T = 100.6



Discussion

- What’s good about the Dyntacs approach?

- What’s bad about the Dyntacs approach?

A Couple of Thoughts on RADAR/Sonar Modeling in Combat Simulations

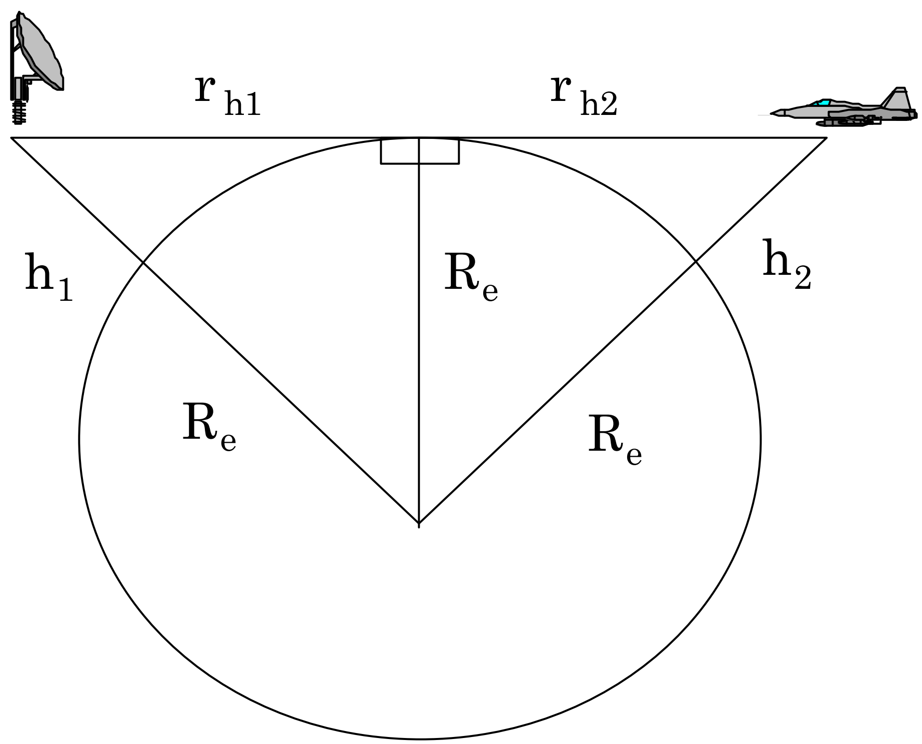
- Big picture ideas
- The radar range equation (RRE)
- Lots of other factors…

- A brief note on the sonar

RADAR

- RADAR = (**RA**dio **D**etection **A**nd **R**anging)
- Simplest=sensor dependent cookie cutter
  - Can extend to each sensor target pair
- Need to check Line of Sight first
- How get acquisition distance? (two approaches)
  - Field data (experimental) or very Hi-Res simulations
  - Radar range equation (physics based)

Does a LOS exist (i.e., is the target OTH)?



Look at left triangle

$$(1)\ R_e^2 + r_{h1}^2 = (R_e + h_1)^2$$

$$(2)\ r_{h1}^2 = 2R_e h_1 + h_1^2$$

$$(3)\ r_{h1} \cong \sqrt{2R_e h_1}$$

$$\therefore\ r_{h2} \cong \sqrt{2R_e h_2}$$

Therefore, range till target comes OTH is $r_{h1} + r_{h2}$

Plugging in Some Numbers

- Usually sensors/targets are in feet, want r_h in miles
- Noting that R_e = 3960 miles and there are 5280 feet/mile we get:
- r_{h1} (in miles) = Sqrt[1.5*h_1 (in feet)] = 1.22*Sqrt[h_1]
- But, radar usually bends "over the horizon" so a common value for R_e is (4/3)R_e
- Therefore, usually see r_{h1} = Sqrt[2*h_1] = 1.41*Sqrt[h_1]
- For nm, get r_{h1} (nm) = = 1.23*Sqrt[h_1]

An Example:

- At what range will a sea-skimming anti-ship missile (at 40 ft) come over the radar horizon for a ship with an antenna at 60 ft?
  = 1.23*Sqrt[40] + 1.23*Sqrt[60]
  = 7.78 + 9.53
  = 17.31nm

- Note: we have done nothing to see if the signal is strong enough yet

Back to RADAR: Challenges With Using Simplified Physics Equations

- Lots of Real World Complications
  - Ducting
  - Refraction
  - Reflections
  - Human effects
  - *"The actual performance of many radars differs from [the RRE] by a factor of between 0.5 and 1.0"*-- *Koopman*
- No matter how detailed your Physics based model is it will ***not*** be predictive. (see DSB)

The RADAR RANGE EQUATION

- What is it?
  - Lots of variations
  - Single pulse (most systems integrate over several pulse (even scans))
    - Often modeled as effective power transmitted rather than single pulse power

Derivation (I)

Equation 5-3
$$I_0 = \frac{P_t}{4\pi R^2} \frac{\text{watts}}{\text{unit area}},$$

where P_t is the transmitted (peak) power in watts and $4\pi R^2$ is the surface area of a sphere of radius R. From the definition of G it follows that the power density on the axis of an antenna of gain G would be

Equation 5-4
$$I_g = \frac{P_t G}{4\pi R^2} \frac{\text{watts}}{\text{unit area}}.$$

Let A_t denote the target-echo area which collects energy from the incident wave and reradiates it *omnidirectionally*. This definition of target-echo area is somewhat arbitrary in that A_t is determined only by the solution of the full radar equation. With this definition, the power received by the target is

Equation 5-5
$$P_g = \frac{P_t G A_t}{4\pi R^2} \text{ watts},$$

and the power density returned to the radar, from the power reradiated omnidirectionally by the target is

Equation 5-6
$$I_r = \frac{P_t G A_t}{(4\pi)^2 R^4} \frac{\text{watts}}{\text{unit area}}.$$

Using the effective area of the antenna, A_e, as a collector of energy, the reradiated power collected by the antenna is

Derivation (II)

Equation 5-6 $$I_r = \frac{P_t G A_t}{(4\pi)^2 R^4} \frac{\text{watts}}{\text{unit area}}.$$

Using the effective area of the antenna, A_e, as a collector of energy, the reradiated power collected by the antenna is

Equation 5-7 $$P_r = \frac{P_t G A_t A_e}{(4\pi)^2 R^4} \text{ watts.}$$

Solving for range, Equation 5-7 becomes

Equation 5-8 $$R^4 = \frac{P_t G A_t A_e}{P_r (4\pi)^2}.$$

If P_o is the minimum detectable power for the radar receiver, then the maximum range, R_m, for detection is the range at which $P_r = P_o$ and Equation 5-8 can be written

Equation 5-9 $$R^4{}_m = \frac{P_t G A_t A_e}{P_o (4\pi)^2}.$$

Units used

- Watts
  - Often expressed in decibels: x dB = $10\log_{10}(x)$
- Square meters or Nautical miles
- Convert as needed (e.g., range in Nm)

Example problem

- Radar parameters
  - effective power transmitted (10^8 watts)
  - antenna gain (10^5)
  - effective antenna receive area (10 meters^2)
  - Detection threshold (10^(-8) watts)

- Target parameters
  - range (10^5 meters)
  - radar cross section = (10 meters^2)

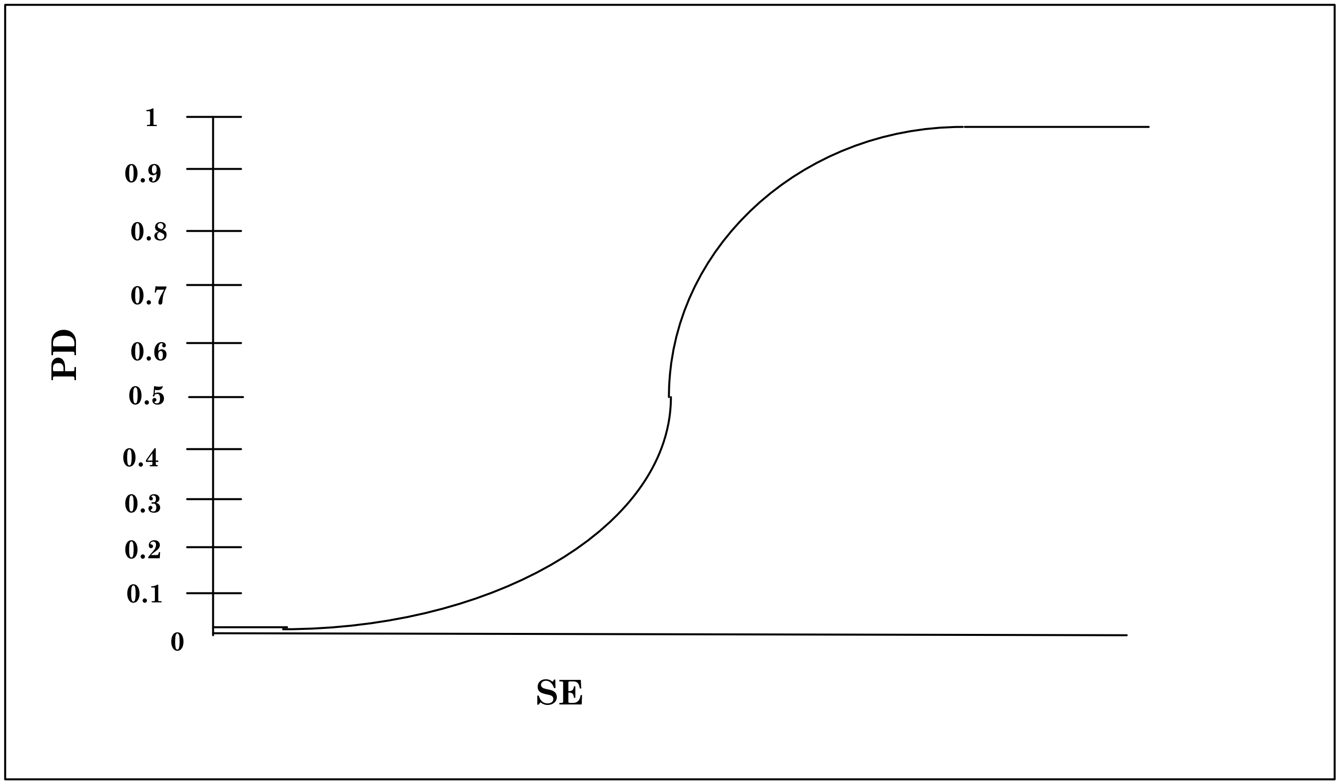
Example calculation

- Power received = $\frac{10^8 \times 10^5 \times 10 \times 10}{16 \times p^2 \times (10^5)^4}$

- = 6.33 10^{-8}

- > DT = 10^{-8}, therefore we have a detection (or could do PD|signal excess)

PD versus Signal Excess



Aspect Dependent

- When need (mission level model)
  - modernization (new plane, sensor, etc.)
  - employment (possible attack missions)
- Picture in Bell's book

RCS as a Function of Aspect

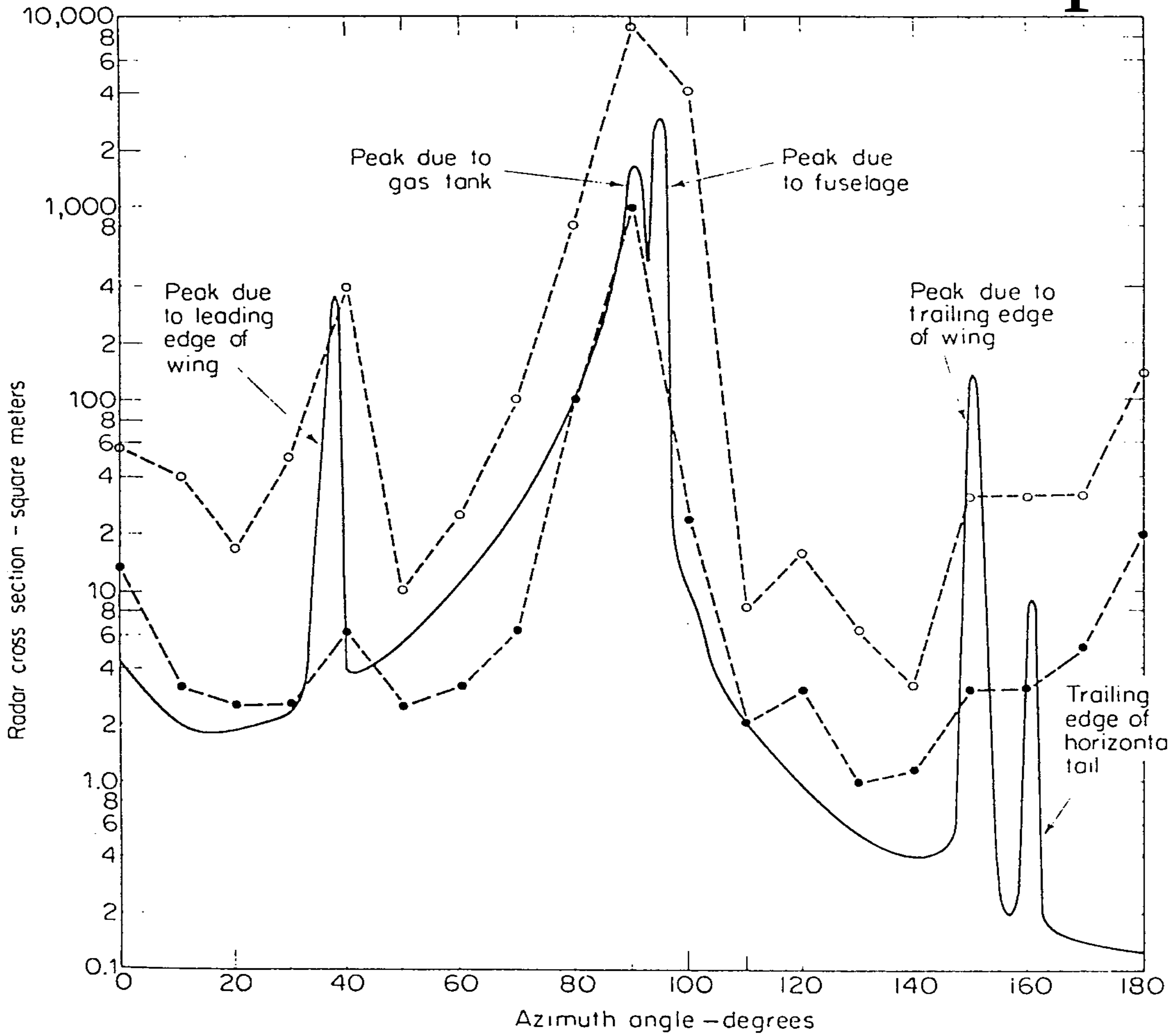


Figure 2.17 Comparison of the theoretical and model-measurement horizontal-p
sections of the B-47 medium bomber jet aircraft with a wing span of 35 m and a leng
is the average of the computed cross sections obtained by the University of

How Model in a Mission Model?

- Each Scan or Time period have a “detection opportunity” event.
- If objects trajectory is know *a priori* (e.g., incoming ASM) can schedule “detection” “lose contact” events based on cumulative probabilities.
- My experience, with lots of dynamic entities making state based decisions it is easier to have lots of periodic “detection opportunity” events--rather than scheduling/descheduling detection events.

Other issues

- Sophisticated processing improves on single scan PD (integrate over multiple scans)
- I have been told real world sensors don’t do as well as equation says
- Difficulties such as multi-path and clutter hard to model--requires detailed ray-tracing and background models
  - Use Doppler shift to improve detection in clutter
- Validation issues (see DSB)
- More detail--beam forming (EADSIM--SUPPRESSOR)
- Jamming (broad band) depends on aspect

Sensor/Tracking Error

- RADAR returns Information on target (with error)
  - Range
  - Range rate--due to Doppler shift
  - Bearing (a function of beam width)
- Usually assume BVN in range and bearing
- Tracking combines (with error) many reports
- Data Fusion combines reports and tracks (with error)

SONAR Modeling

- Harder than radar
  - particularly transmission loss
  - *"Sea water is not uniform in density, pressure, temperature, or salinity, and all of these characteristics have important effects on sound propagation through the sea"*--Naval Operations analysis
- The basic equations (active/passive)
- Sound bends (a lot) in the sea

More complicated than RADAR

- Similar equation, Sonar
- Transmission losses much more complicated (bending)
  - direct path (spreading)
    - Significant Shadow Zones
  - bottom (or surface) bounce
  - Convergence Zones

Basic Equation

- Variables
  - Equipment
    - Source Level (SL)
    - Self-Noise Level (NL)
    - Detection Threshold (DT)
    - Receiving Directivity Index (DI)
  - Parameters caused by the sea
    - Transmission Loss (TL), due to spreading and absorption
    - Reverberation (RL)
    - Background Noise (BN)
  - Parameters of the target
    - Target Strength (TS)
    - Target source Level (SL)

Basic Equation (Use Decibels)

- Passive (1 way transmission)
  - Signal/Noise = SL - TL - (BN*-DI)
  - Detection is a stochastic variant of Signal Excess = "Signal - DT"
- Active
  - Signal/Noise = SL - 2TL +TS +(BN*-DI)
  - Detection is a stochastic variant of Signal Excess = "Signal - DT"
- * BN can be ambient noise, self-noise, or reverberation in active case

Sound bends with velocity

- Towards slower velocity
- Huge operational impact

Sound Velocity Profiles (SVP)

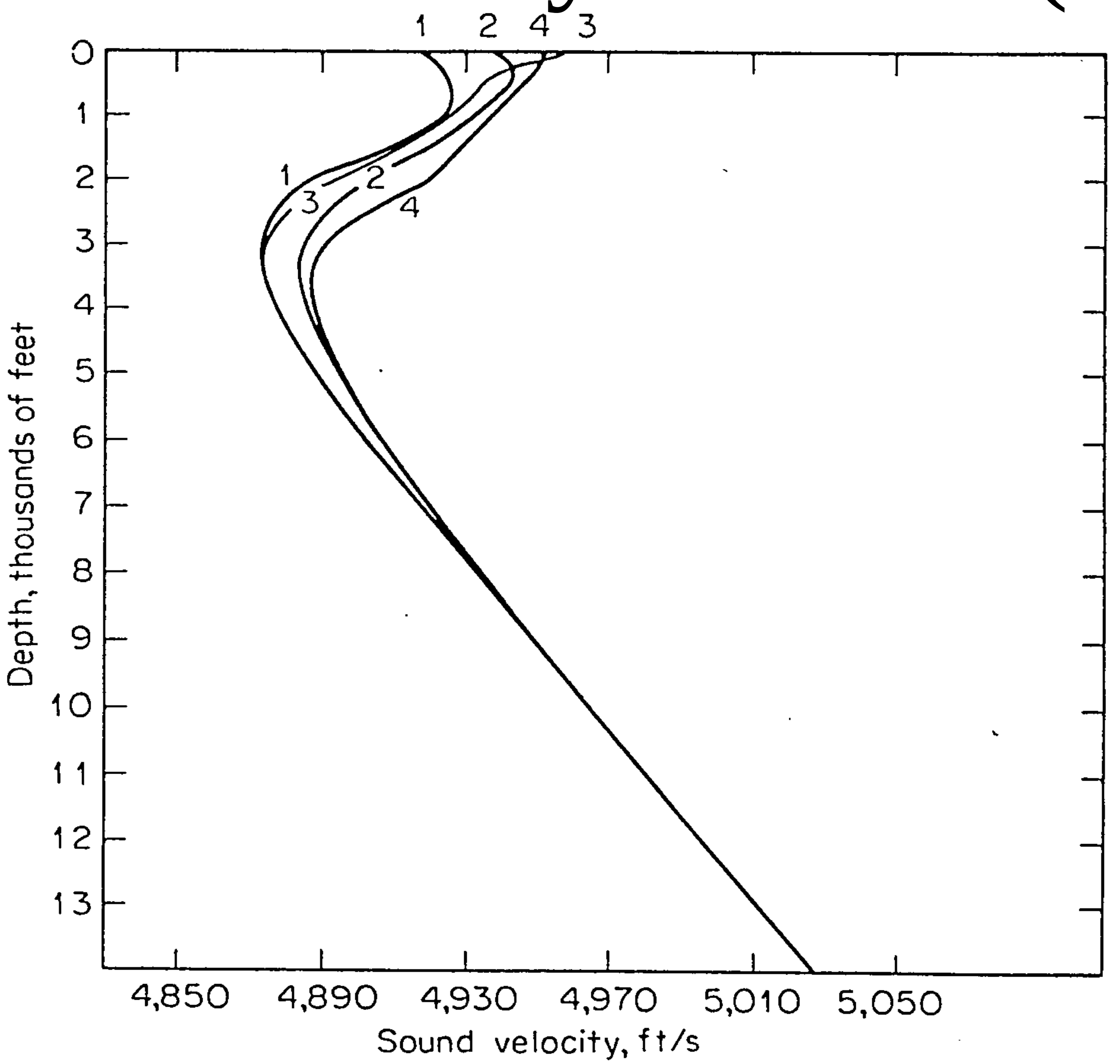
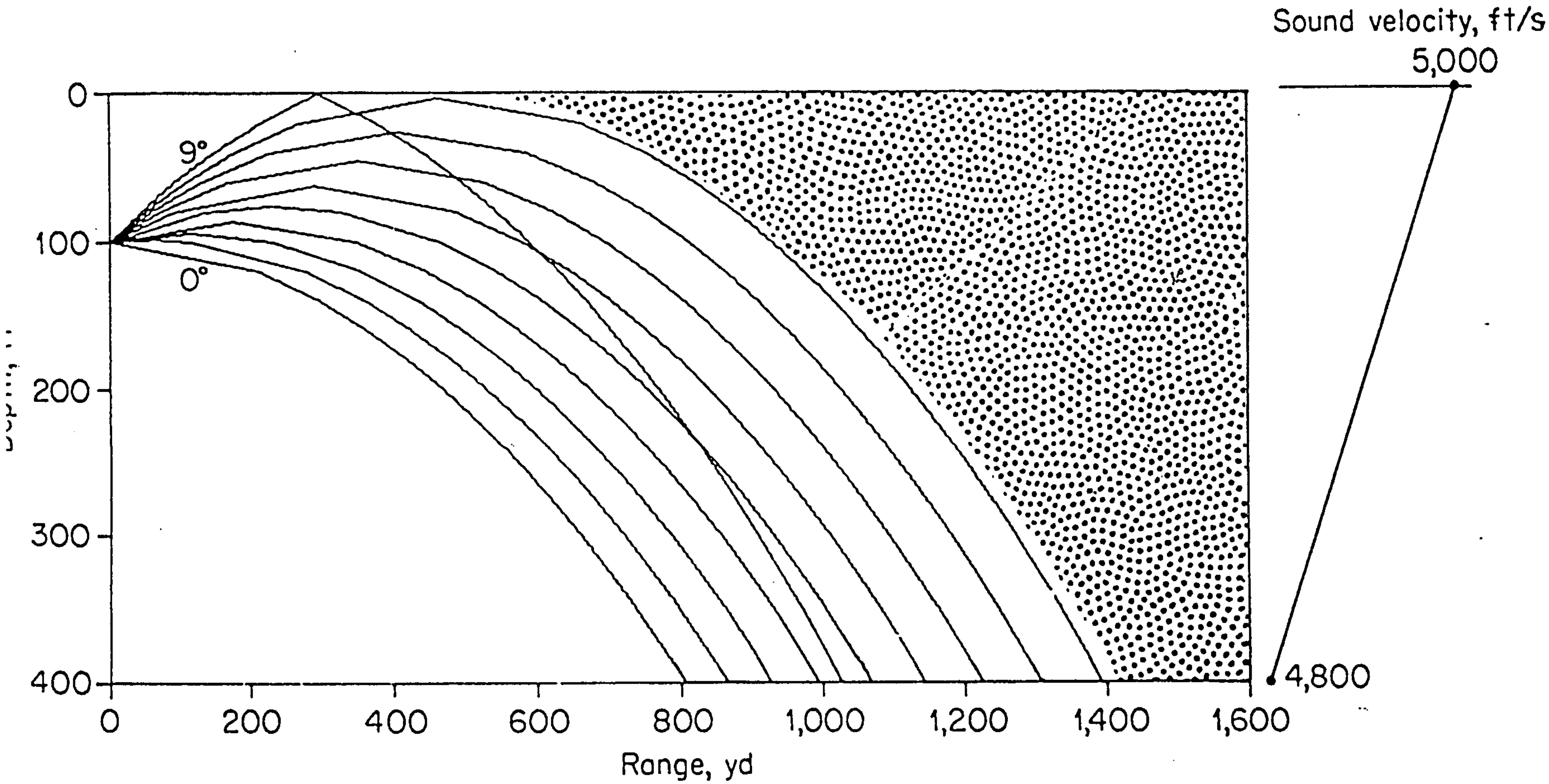


fig. 5.14 *Average velocity profiles in different seasons in an area halfway between Newfoundland and Great Britain. Latitu˙ 43 to 55°N, longitudes 20 to 40°W. (1) Winter (2) Sp. ˛. (3) Summer. (4) Autumn. (Ref. 47.)*

A Shadow Zone



*;. **5.26** Ray diagram for a source at a depth of 100 ft in the linear gradient shown at*
: right. St' led area is the surface shadow zone.

Typical Deep-ocean Sound Channel

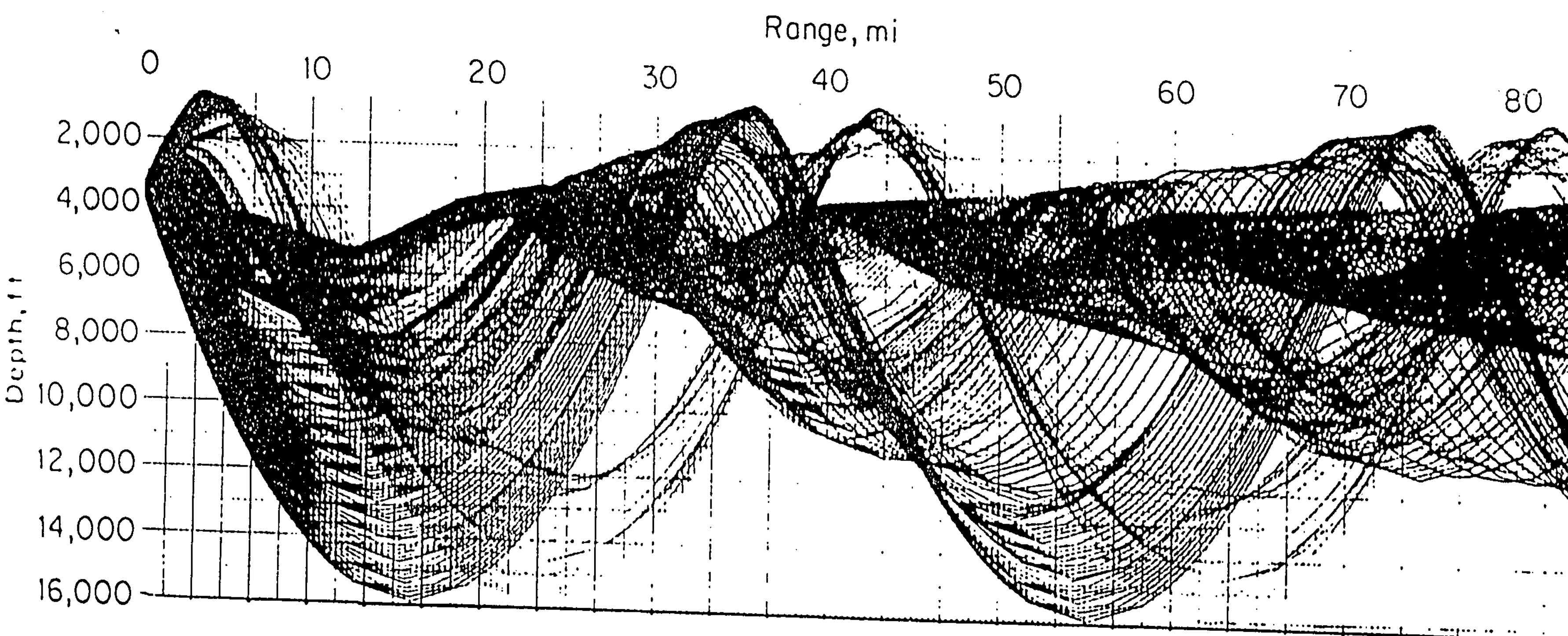


fig. 6.10 *Ray diagram of the deep-ocean sound channel for a source near the axis. Reflected rays are omitted.*